# Chapter 2
# "Organization": Its Conceptual History and Its Relationship to Other Fundamental Biological Concepts

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**Abstract** The conceptual history of the term "organization" begins in Medieval times with the reception and transformation of Aristotle's philosophy of life. It designates the corporeal structure and conditions of identity of natural "organic bodies," a term that had been used to refer to living beings since antiquity. The term played an important role in specifying the ontological status of living beings. At the same time, it offered a basis for their mechanistic understanding. Starting with mechanistic models of life in the second half of the seventeenth century, "organization" and "life" were increasingly used interchangeably. This conjunction of meaning transformed "living beings" into "organisms." Within physiological accounts of the eighteenth century, the living organization was compared to a causal cycle of interdependency. Philosophically, this conjunction was adapted at the end of the century in Kant's philosophy of "organized beings of nature" in which he located the idea of causal cyclicity within a teleological framework and specified an "organized being" in causal terms as a system of interacting and interdependent parts characterized by functional closure. Thus, "organization" refers to the constitution of living beings as a particular kind of causal system. In the nineteenth century, the term achieves the status of a signal word for the life sciences and starts being applied in a wide variety of contexts, from comparative anatomy to physiology and ecology. It was supplemented by two other fundamental notions, namely, "regulation" and "evolution," the first referring to the stabilization and the second to the long-term transformation of natural organizations. The twentieth century saw a further intensification of the complementarity of the perspectives associated with these three terms. Finally, in recent years, a substantial improvement in understanding the causal structure of "organization" was achieved by analyzing it in terms of the "closure of constraints."

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## 2.1 Introduction

For a very long time, "organization" has been a central concept in biology. Since antiquity, the material basis of a living being has been called "organic body" ("corpus organicum"). For Aristotle, this meant that the body is an instrument ("organon") of the soul (Bos, 2003). However, since late antiquity, especially since the writings of Galen, an "organic body" was understood as an integrated system in which the parts mutually depend on one another. Thus, they were seen as instruments not only for the soul but also for their own interdependent activity. Galen compared the working order of the organic body to a "symphony" and explained it as "sympathy" or "synergy" in the sense of a "functional organization" (Siegel, 1973, p. 129; Toepfer, 2011a, vol. 2, p. 779). However, the term "organization" was not applied to this functional organization prior to the Middle Ages. Surprisingly, there was apparently no original semantic connection between the Greek expressions for "organization" and "organ": whereas the former was used in the sense of "forming," the latter had a functional meaning from the beginning. Both expressions have therefore been described as "semantically autonomous" (Wolf, 1971, p. 31). Only in the course of their later development were the two notions semantically unified. Starting with mechanistic models of vital processes in the second half of the seventeenth century, "organization" and "life" were increasingly used interchangeably. Since the end of the eighteenth century, "organization" has thus predominantly been understood as a characteristic of living beings, becoming a signal word for the animate world and its scientific analysis. The assumption that it was the organization of their body that constituted the defining characteristic of living beings led to the transformation of "living beings" into "organisms." However, on the level of individual organisms, this did not happen before the end of the eighteenth century; before that, "organism" was used (in parallel to "mechanism") in the sense of "organization," referring to the abstract structure of organisms, not specific individuals (Cheung, 2006). In the nineteenth century, it became common practice to equate life with organization: in the words of the early Neo-Kantian philosopher Kuno Fischer, "Life is organization, self-organization."(Fischer, 1865, p. 534) A few decades later, at the beginning of the twentieth century, "biology," the label that had been given to the science of life, was defined as the "study of the organization of the living" with "organization" being the name for "the association of different elements according to a uniform plan for a common effect" (Uexküll, 1903, p. 269). However, for the longer part of its history, "organization" has functioned as a dummy concept or placeholder for a theory of the living still under negotiation. It was embedded in an explanatory approach in which living beings were seen as functional systems composed of interacting parts. It was only during the last decades that a full-fledged theory of organization was proposed, enabling the term to fulfill the theoretical role it was meant to fulfill since the 1800s.

## 2.2 The Conceptual History of "Organization"

The term "organization" first appeared in medieval Latin. The word is related to the Greek expression "ὀργάνωσις" meaning "formation, arrangement." The Greek term was used, for example, by Sextus Empiricus and Porphyrios in late antiquity, in the second and third century AD, respectively. Whereas Sextus Empiricus used the Greek expression in his treatise *Against the Logicians* in the more general sense of "arrangement" or "conjunction" (Adversus dogmaticos, 7, 126; Engl. transl. Bett, 2005, p. 114), Porphyrios applied it to the more specific context of bodily structures that living beings of distinct categories have in common (in order to argue against the practice of eating meat): "Almost everyone agrees that animals are like us in perception and in organisation generally with regard both to sense-organs and to the flesh" (De abstinentia 3, 7; Engl. transl. Clark, 2000, p. 84).

Later, in the High Middle Ages, the Latin term "organization" appears in several texts by Thomas Aquinas, especially in reference to Aristotle's second book of *On the Soul*. Here, Thomas closely associated the term with the formation of organic bodies ("formatio et organizatio corporis"; In III Sententiarum distinctio (1254–56): dist. 3, qu. 2, art. 1; dist. 4, qu.2, art. 1) and claimed that, for Aristotle, "organization" was the basic principle of living bodies ("de ratione corporis vivi est organizatio"; In IV Sententiarum distinctio (1254–56) dist. 10, qu. 1, art. 2, quaestiuncula 3, sed contra 2). Furthermore, he stated that the term referred to a multitude of parts and was relevant to the form of the body. In these and other passages, Thomas attributed the concept of an "organic body" to Aristotle, in the sense of a body consisting of a diversity of organs; only those bodies which feature this inner diversity are "organic bodies"; this diversity was said to be "necessary" for living bodies: "dicitur corpus organicum, quod habet diversitatem organorum" (Commentarius in libros de anima II et III: 2, 1, 20 (No 230)). Following these lines of thought, future authors even referred to Aristotle as the "father of animal organization" (Schiller, 1978, p. 84).

However, there is some debate as to whether Aristotle actually saw living beings as organisms (Bolton, 1978; Bos, 2003). In *On the Soul*, the book referred to by Thomas Aquinas, Aristotle claimed that the soul is the form of a natural body that potentially bears life. However, according to Aristotle, the soul as the principle of life was not directly related to the disposition of the organs in the body. For Aristotle, the body was an organ or an instrument of the soul but not necessarily an organized being consisting of a diversity of interacting organs. He did not elucidate the relationship of the soul to the diversity of its organs. "Organic," a term Aristotle apparently introduced into the Greek language, was used by him in reference to something "instrumental." Here, the term does not refer to a diversity of organs and does not even imply an "endowment with organs." Consequently, in the modern and contemporary sense, the concept of organization was not an inherent part of Aristotle's philosophy of living beings.

Aristotle had no specific term for the arrangement or disposition of the organs that provided essence and unity to living beings. In Aristotle's terminology, this function is fulfilled by the soul. However, there are good reasons to assume that the Aristotelean "soul" corresponds well with the medieval and modern idea of organization since both refer to the essence and unity of a living system. There are four particular parallels between the concepts of "soul" and "organization" (Quarantotto, 2010): (1) like the soul, the organization is not itself a body, but a property belonging to the body; (2) soul (or organization) and body do not exist independently of what possesses them, they are not self-sufficient autonomous entities; (3) both are considered the principle of unity and identity of the body that they organize/endow with soul; and (4) soul and organization are both explanatory principles for fundamental organic activities such as movement—the reason why animals have the capacity to move is found in their organization or endowment with a soul.

Thus, prior to the scientific revolution in the seventeenth century, "soul" was a concept perfectly equipped to fulfill the explanatory role that was later taken on by "organization." In fact, the latter term only came into frequent use during the seventeenth century. Until then, it was employed nearly exclusively in the context of scholastic discussions on the changing arrangement of parts in embryonic development.

That situation changed in the early seventeenth century, when, in a commentary on Aristotle's *On the Soul* (1600), "organized" was equated with the state of "potentially having life" (Collegium Conimbricense, 1600, p. 55; for the context, see Des Chene, 2000). Henceforth, the term "organization" entered the academic language, especially as a result of debates on the value of mechanistic models for living beings.

At the beginning of this debate, "organization" was not yet in the position to become the fundamental principle of life. For the Cambridge Platonist Henry More, for example, "organization" was not equivalent to the living state of a being. He postulated a "Plastical Power" that "organized" "duly-prepared Matter," as he called it, "into life" (More, 1659, p. 46). Thus, the "mere organization of the Body" (ibid., p. 107) was not enough to constitute life; this was a merely *mechanical* organization—or, in More's terms, "matter mechanically organized" (ibid., p. 109). Thus, More still differentiated between life as "being ensouled" and life as "organization."

Three years later, in 1662, Joachim Jungius, a mathematician and philosopher of science from Hamburg, announced that "true organization alone" was at least sufficient for plants to perform their life functions of nutrition, growth, and reproduction. Jungius followed Descartes as he denied plants a soul, arguing that their life functions could be explained by the mere disposition and arrangement of their parts: "vero organisatio sola sufficiat" (Jungius, 1662, part. 2, sect. 3). To my knowledge, this is the first instance in which "organization" and "life" were used interchangeably. The exact wording was later resumed by La Mettrie in his description of the relationship between the mental and the material aspect of the brain: "The organization, is it really sufficient for everything? Once again, yes" (La Mettrie, 1747, p. 180).

In the period of dominant mechanistic thinking from the mid-1660s onward, several authors accepted the equation of life and organization. Robert Hooke, for example, used the term "organization" in English. Presumably inspired by his microscopic observations of plant tissues, he claimed that there was an organization common to all vegetables ("the same Schematism or Organization that is common to all Vegetables"; Hooke, 1665, p. 116). In a similar vein, Francis Glisson argued in 1672 that the difference between plants and animals and other bodies could be deduced from their "organization." Thus, life had no cause other than the organization of bodies (Glisson, 1672, p. 226; for the context, see Hartbecke, 2006, p. 165). Additionally, in an important and well-known ontological argument, John Locke reflected on the conditions of identity of living beings whose parts are constantly being exchanged whereas the entirety of the system remains the same. Locke used the term "organization" to refer to this bodily property that always persists even as its parts are exchanged (Locke, 1689, p. 331).

In the 150 years between 1650 and 1800, which could be viewed as the formative period of biology, the ancient principle of life, the "soul," was gradually replaced by "organization." Organization became the central explanatory concept for biology. This was the conceptual revolution at the beginning of biology, which at the same time maintained the ontological specificity of life phenomena, and their mechanistic explainability starting from uniform principles transformed the study of life into an explanatory endeavor that maintained rests on a unifying principle that provided: life was equated with being organized (see also Jacob, 1973, Chap. 2). An important element of this revolution was a reversal of the relationship between the concepts of "life" and "organization": in the seventeenth century, "life" was the more fundamental notion and the living state was thought to somehow determine the organization of the body. However, during the eighteenth century, it was established that it actually works the other way around, a notion that persists until today: "organization" now forms the basic concept from which the determination and consequently the analysis starts; "life" becomes a phenomenon derived from "organization" (see Schiller, 1978, p. 24).

In the first half of the eighteenth century, however, this equation was not accepted by all authors. In order to integrate the living world into the nonliving (and thus advocate for the possibility of a spontaneous generation of living beings), some considered all parts of nature to be organized. This was the position held by Leibniz, for example. He reasoned that since everything is arranged by God, every piece of matter is organized ("la matiere arrangée par une sagesse divine doit estre essentiellement organisée partout"; Leibniz, 1705, p. 342). In the 1720s, this view is supported by microscopic investigations and descriptions of the regular crystalline structure in minerals (see, e.g., Bourguet, 1729, p. 58: "tout est organisé dans la matière"). Thus, until the middle of the eighteenth century, there were influential authors for whom the concept of organization served to unify rather than to separate realms of nature.

For the life sciences, "organization" increasingly served as an important explanatory concept. This is especially true for mechanical approaches toward the generation and transformation of living beings. In fact, in the mid-eighteenth century, it was preformationism, i.e., the idea that the forms of living beings are already existent in their germs, that mainly contributed to the diffusion of the concept (Schiller, 1978, p. 40). In reference to the preexistent structures in the germ, its "organization," it was possible to explain the emergence of complex adult forms as "development."

In the eighteenth century, the idea of organization was mainly associated with mechanical understandings of life and preformationist accounts of individual development. In this context, the term mainly referred to the specific body plan of organisms and could therefore be used not only in developmental studies but also in natural history for the classification of organisms into taxonomic groups. Linnaeus, the master of this approach, defended the view that "organization" was a specific concept within the life sciences, presumably because matter in living beings, in contrast to nonliving ones, was specifically arranged into recurrent, taxonomically significant structures. In the tenth edition of his *Systema Naturae*, the association of "organized" and "living" was made explicit and formalized typographically by characterizing plants and animals as "organized and living" (*organisata & viva*), whereas stones were seen as merely "composite" (*congesta*) (Linnaeus 1758, p. 6). In the mid-eighteenth century, several authors stressed the explanatory value of "organization" in different fields within the life sciences: in 1750, John Turberville Needham argued that vitality, sensation, and thinking appear to be an immediate consequence of "organization" (Needham, 1750, p. 375). In 1772, Voltaire famously defined life as organization: "La vie est organisation avec capacité de sentir" (Voltaire, 1772, p. 55). Some years later, Diderot claimed that the soul is nothing but organization and life: "L'organisation et la vie, voilà l'âme" (Diderot, 1778, p. 358). At the end of the century, Christoph Girtanner also directly connected the living state with being organized: "Les mots organisé & vivant sont, selon moi, des synonimes" (Girtanner, 1790, p. 150). Even in Kant, in his *Opus postumum*, one can find this equation of "being alive" and "having an organization" (Kant, OP., AA XXI, p. 66). In his major work on the epistemology of biology, the *Critique of Judgement*, Kant (AA V) called living beings "organized beings in nature," although he avoided the term "living" because it had a terminological use in his ethical writings.[1]

Since the beginning of the nineteenth century, "organization" has been regarded as one of life's most essential aspects. It proved to be valuable for the self-understanding of biology as an independent natural science. This was particularly evident in situations where life was either reduced to the merely mechanical or explained with additional supernatural "life forces." In the mid-nineteenth century, Claude Bernard essentially relied on the concept of organization when he rejected vitalistic approaches. According to Bernard, all manifestations of life are not to be derived from a mysterious life force, but from "the phenomena of organization" (Bernard, 1867, p. 138). At the beginning of the twentieth century, in light of the growing struggle between mechanism and vitalism, the study of life was simultaneously confronted with the postulation of mysterious vital principles and reductionist views that denied any peculiarity of vital phenomena and their scientific explanations. In this situation, "organization" was propagated as a concept that offered a

[1] However, things are complicated in Kant as he also has the concept of nonliving natural purposes which are the plants. Hence, for Kant, not all organized beings are living. I thank Gertrudis Van de Vijver for pointing to this; see also Piché, 2001.

third way between these two metaphysical positions and, thus, was seen as a way out of the fundamental dispute in theoretical biology. On the one hand, the assumption of a central guiding vital force was considered unnecessary, because, if seen as functional organizations, living beings and the orderly processes within them could be described as the outcome of a decentralized structure of interacting parts. On the other hand, "organization" was understood (in the Kantian sense) as an additional principle that is not part of a purely mechanical approach, because it added the aspect of integrating isolated causal relations into a coherent functional whole. In 1900, Oscar Hertwig argued that the explanation of life should neither introduce mysterious forces nor follow the "mechanistic dogma," according to which "life with all its complicated phenomena is nothing than a physico-chemical problem" (Hertwig, 1900, p. 24). Instead, Hertwig argued for recognizing "that life is based on a peculiar organization of the substance" (ibid, p. 4). Via the concept of organization, biology could thus take a third path and navigate between the approaches of vitalism and mechanism, thus securing biology's status as a natural science and its methodological autonomy from physics (see also Wolfe's contribution to this volume). In the twentieth century, biological research programs that aimed to find life on other planets and create life in the lab found the organizational approach to be more stable than any purely material or molecular characterization of life: "The peculiarity of life is not due to some chemical mystery but to organization" (Bertalanffy, 1928, p. 68–9).

Hence, at least for 250 years, "organization" has been one of biology's basic if not one of its most fundamental concepts that which explains what life is. This poses a question: What is "organization"? What does the term actually mean?

## 2.3 The Meaning of "Organization"

A fairly good, but still very open, definition can be found in the *Encylopédie*: "Organization" is defined as "the arrangement of parts that constitute a living body" (Anonymous, 1765, p. 629). Thirty years later, Kant, in a letter to Sömmering, contributed an important amendment: he expanded this definition by including purposiveness. For him, "organization" was "the purposeful and in its form persistent arrangement of parts" (Kant, 1795, p. 33). In his works on natural philosophy, Kant had a very specific understanding of purposefulness. As is well known, Kant stated that in a thing as a natural purpose, the parts are "reciprocally the cause and effect of their form" (Kant, 1790, p. 373). This means in a thing as a natural purpose the parts' *very existence* depends on the system's other parts. Kant stresses this ontological dependency in another passage: "For a body […] which is to be judged as a natural end in itself and in accordance with its internal possibility, it is required that its parts reciprocally produce each other, as far as both their form and their combination is concerned, and thus produce a whole out of their own causality" (ibid.).

Kant did not indicate the origin of his idea of reciprocity as a condition for a thing to be a natural purpose. However, similarities in the wording and his personal contacts suggest that the idea was inspired by the Leiden physiologist Herman Boerhaave (see Toepfer, 2011b). In 1727, Boerhaave provided a definition for the concept of an "organic body" in which the decisive moment is the interdependence of the parts (*harum partium actiones ab invicem dependent*; Boerhaave, 1727, p. 3). To be sure, the emphasis on reciprocity as a hallmark of organic systems has its roots in Antiquity (see Toepfer, 2011a, vol. 3, pp. 738–763). However, only with the physiological theories since the end of the seventeenth century did it acquire a fundamental role in the identification and definition of living beings. This process took place in parallel with the introduction of the concept of "organism." Georg Ernst Stahl, who proposed this notion in 1684, already described the relationship of the parts in an organism as an "adaptation of forms" (*aptatio configurationis*) and a dynamic interaction of a single part with the others (*cum aliis partibus cohaerens, conspirans, atque communicans*) (Stahl, 1707, p. 17). The parts in an organism would act "reciprocally and together" (*mutua & socia*) and thus be interrelated (ibid.). According to Stahl, the whole complex of the diverse organs in an organism forms a functional unity since the ultimate purpose of all movements is to preserve the body. The concept of "organism" thus establishes a causal model for a functionally closed and self-referential system of heterogeneous components. During the first half of the eighteenth century, Boerhaave and other mechanistically minded physiologists invoked the image of a "circle" (*circulo quasi*) for the causal pattern of organic systems, consequently firmly anchoring any discussions of causal reciprocity in physiological language (*mutuas causæ vices & effectuum gerant*) (Boerhaave, 1708, p. 11).

This physiological understanding of the interactions within an organic body formed the background for Kant's understanding of "organization" in terms of causal reciprocity. Kant's philosophical contribution was the integration of teleology into this causal understanding of natural systems of interdependent parts as well as the clarification of the peculiar metaphysical and ontological status of organisms or, in his terms, "things as natural purposes," with respect to the explanatory level of causal mechanisms. In doing so, in combining teleology and cyclicity, Kant gave a justification of teleology within biology as the science of cyclical organized systems: the teleological way of thinking by focusing on outcomes of processes is justified in biology because biology is the study of systems consisting of interdependent parts in which the final state of one process is important for the existence of the other parts of the system and ultimately for its own maintenance (as a type of process or part).

Kant's philosophy of the organic was widely received in the years around 1800. Disciples of Kant gave explicit definitions of "organization" with Kant's philosophy in mind, for example: "Organization is the disposition of a body in which every part is at the same time means and ends to all the others" (Schmid, 1799, p. 274). Not only philosophers but also practicing biologists accepted this foundational role of reciprocity and teleology for the specification of their objects of study. One example by a famous author: "A living body is a natural organized body composed of different kinds of parts which act and react upon each other" (Lamarck, 1797, pp. 249–50). Lamarck repeatedly formulated concise sentences which express the close connection between the state of being alive and organization or order. For him, life constitutes a "physical phenomenon resulting from the order of things and from the state of the parts," their "organization" itself being a "physical phenomenon" (Lamarck, 1815, p. 60; 122; see Schiller, 1978, p. 70). "Life" was explained as an "ensemble of functions" with the functions being nothing but "acts of the organization and its pars" (ibid., p. 59). As these short quotations make clear, Lamarck had a dynamical understanding of "organization"; in his view, it is linked to movements caused by the arrangement of the parts within a body.

In the first half of the nineteenth century, however, the static interpretation of "organization" proved to be at least as important as the dynamic view.[2] In comparative anatomy, one of the dominant research areas at that time, "organization" was understood as the "disposition" of the parts in an organic body; it referred to the configuration of the parts, the "body plan." Anatomy with its focus on the spatial arrangement of parts within a body has even been called "the science of organization" (Schiller, 1978, p. 88). In this context, the analysis of the "organization" of body plans formed the foundation for the classification of animals into larger groups. For Georges Cuvier, one of its main representatives, comparative anatomy is the study of "the laws of organization of animals and of the modifications this organization shows in different species" (Cuvier, 1817, vol. 1, p. v). In Cuvier's taxonomic system, the arrangement of the nervous system was of particular importance; it provided the basis for the classification of all animals into four main "branches" (see Figlio, 1976; Guillo, 2003). Here, "organization" was an important notion because it stressed the interdependence of the parts. In comparative anatomy, this interdependence was not primarily a causal notion but referred to the observation that traits of the body plan covary and do not exist independently from one another. Besides that, "organization" was also used as a measure for the complexity or "degree of perfection" of body plans. Even Charles Darwin, who was generally skeptical of the idea of progress in the history of life on earth, held the view that natural selection would result in an "improvement" that inevitably led to "the gradual advancement of the organization" (Darwin, 1860, p. 117).

For the philosophy of biology and its reflection on the ontological peculiarity of living beings, the important aspect was not this morphological concept of organization but the physiological meaning of the term. It was in the years around 1800 that the essential aspects of the concept were established—those that have persisted ever since. "Organization" now referred to the disposition of the parts in a certain type of causal system; the pattern of causal interactions has the form of a cycle because the parts mutually depend on one another's influence, resulting in a functional "closure."[3]

[2] Therefore, most of the historical accounts of the concept of "organization" in the history of biology focus on this aspect (see Figlio, 1976, Schiller 1978, and Guillo, 2003).

[3] This currently prominent term that is most often derived from Piaget (1967, p. 182) also has its roots in early nineteenth-century reflections on the ontological status of organisms. Georges Cuvier, for example, put it this way: "Tout être organisé forme un ensemble, un système unique et clos, dont toutes les parties se correspondent mutuellement, et concourent à la meme action définitive par une réaction réciproque" (Cuvier 1812, vol. 1, p. 58).

Later definitions elaborated on these points, especially by highlighting the self-referential character of organizations. In 1928, Helmuth Plessner explained: “Organization is the mode of existence of the living body, which must differentiate itself and through which it generates the inner teleology according to which it is formed and functions” (Plessner, 1928, p. 170). Thus, an organization consists of differentiated functional parts, which, through their activity, generate and permanently regenerate the entire system. The same point was expressed in the theory of autopoiesis since the early 1970s, in which the “living organization” was characterized as a perpetual self-regeneration (Maturana et al., 1974). In this tradition, organization was defined as “the complex of interaction and properties of structure that make the perpetuation of structure possible” (Kolasa & Pickett, 1989, p. 8837).

Many authors have stressed the close connection between the concept of organization and teleology (except Maturana and his co-workers). Following Kant, one could say that “organization” and “function” or “purpose” go hand in hand: wherever there is organization in nature there is function and vice versa. As John von Neumann once said in conversation with Colin Pittendrigh, “Organization has purpose; order does not” (Pittendrigh, 1993, p. 20). Since functional reasoning and exploring purposes are essential to the domain of biology, it makes sense that “organization” has become a fundamental concept for that science—in contrast to physics, as “the physical sciences don’t deal in function” (Wicken, 1987, p. 40). Consequently, “organization” and “function” are frequently regarded as crucial to any attempt to justify the autonomy of biology as a science. Since Kant, this position has been defended by many authors, and teleology was even defined as the “philosophy of biology” because “the organism requires teleological consideration” (Kühnemann, 1924, p. 494).

It is a striking feature of biology that functions have been ascribed to living systems long before the causal pattern of their working order had been understood. Surprisingly, the basic inventory and supposition of functions have changed very little throughout the long history of biology. In fact, Aristotle had already named them: *nutrition*, *growth*, *movement*, *sensation*, and *reproduction*. However, it took more than 2000 years before biology began to understand the way in which they are realized in living beings. Functional knowledge is therefore a one-way kind of knowledge; it reduces the complexity of a system without necessarily having a complete understanding of it. Or, in other words: “organization [and hence function] emerges as a problem when there is too much knowledge in one direction and too little in another” (Beckner, 1959, p. 10).

The integrative power of the concept of “organization” in biology can also be demonstrated by explicating the fundamental properties of living beings as based on this concept. Metabolism, reproduction, development, metamorphosis, and evolution are fundamental aspects of life that can be described and analyzed, respectively, as maintenance, transmission, expansion, individual transformation, modification, or as the supraindividual transformation of organization. Based on this universal applicability, from cell theory to evolution, “organization” has been called “the key concept at all levels” for the life sciences (Figlio, 1976, p. 34).

## 2.4 "Organization" as One of the Three Basic Principles of Biology

"Organization" refers to the constitution of a system of interdependent parts. Two other important aspects of such a system that are related but not solely reducible to its constitution refer to the *permanence* and the *transformation* of the system. In well-known biological terms, they are called *regulation* and *evolution*. The three concepts refer to related but different aspects of organized systems: the causal pattern of their constitution, the capacity to control their relationship to the environment, and the potential for long-term transformation. The general meaning of all three principles operates on the same level of abstraction.[4]

*Organization*, in the systems-theoretical, Kantian tradition, essentially refers to the mutual dependence of parts in a system. *Regulation* refers to the stabilization of an organization by controlling environmental influences. Basically, regulation covers three processes: (1) supplying the system with necessary materials and other factors from its surroundings, (2) protecting it from detrimental influences, and (3) coordinating and integrating all the processes within the organized system. Taken together, they ensure the maintenance of the system, its preservation, and its perpetuation through time by managing the system's relationship with the environment. However, controlling the relation to the environment is not a conceptually necessary feature of organized systems. We can think of organized systems that are not regulated. Ecosystems might be an example for systems that are most certainly organized as their parts depend on each other. However, at least conceptually, we may think of them as not being controlled but more vulnerable to disturbances than organisms. In simple terms, *evolution* can be defined as the transgenerational transformation of organizations due to differential reproduction that is due to selection or genetic drift. The distinctness of "evolution" as a fundamental concept might be less controversial. Of course, we can imagine organisms that do not evolve, and most biologists did so until 1859.

The introduction of these three fundamental concepts in biology, organization, evolution, and regulation can be related to three conceptual turns or even "revolutions" in biology. They took place in the eighteenth, nineteenth, and twentieth century, respectively. The first is the revolution that established biology as a distinct scientific discipline at the end of the eighteenth century. It resulted in the conception

[4] There have been several attempts to separate the aspects of organization, regulation, and evolution of systems. Especially the relation between organization and regulation has been investigated from different angles, i.e., from the angle of economics with the distinction between internal order (organization) and external interventions (regulation) (Sombart, 1925) or the attempt to distinguish general systems theory from cybernetics (Bertalanffy 1951) or the efforts of autopoiesis theory to differentiate between (internal) self-organization and (external) control (Varela 1979). In all these cases, organization concerns the system-constituting internal structure of a dynamic entity, the regulation of its relation to the environment, especially the mechanisms of maintenance in the face of disturbances. For recent attempts to connect organization, closure, and regulation, see Di Paolo (2005) and Bich et al. (2016).

of living beings as organisms. The second revolution was connected to evolution, to the insight that all life on earth is united in one all-encompassing process of transformation. The third revolution, the regulation revolution, took place mainly in the middle of the twentieth century and resulted in the description of organisms as cybernetic systems of control and information flow comparable to man-made machines.

One may think of organization, regulation, and evolution as a rather symmetrical trio: "organization" as the central category concerns the constitution of a system, "regulation" its stabilization, and "evolution" its transformation. However, it is also possible to derive the concepts from one linear argument. This argument begins with "organization" as the fundamental descriptive term for the constitution of living systems. It basically identifies a cycle of interdependent processes. Apart from this internal cycle, which grounds Kant's internal purposiveness, there is an external cycle, a cybernetic feedback cycle that relates the system to its environment and stabilizes the system—the fundamental point of regulation. Regulation is directed toward the perpetuation of the system in time. This can be realized through two mechanisms: by stabilizing the individual system or by its multiplication, by the production of similar systems. Thus, we have two forms of self-preservation in organized systems: One is the regulation that consists in the preservation of individual systems, the maintenance of the dynamic state of an individual organism by devices for nutrition and protection. The other is preservation by multiplication of organizational types, which biologists call *reproduction*, the maintenance of the organizational structure of an individual by its multiplication in new individuals with a similar organization. In this view, reproduction is a preservation strategy by means of perpetuating an organizational type. Ironically, this most effective way of preservation has resulted in the vast process of transformation we call evolution.[5] Therefore, reproduction leads to two contradictory consequences: On the one hand, it emerged as the most efficient means of self-preservation ("preservation by multiplication"). On the other hand, however, since it allows for variation (as mutations are inevitable and often even functional), this eventually results in the transformation of these systems. Ironically, preserving organization therefore means to transform it. As Paul Valéry surmised in an elegant and paradoxical formula: "Bios. Se transformer et transformer pour conserver" (Valéry, 1933, p. 755).

Thus, according to this argument, evolution is a derived feature of organized systems and regulated with respect to their maintenance. By seeking to maintain their systems through the most effective means at their disposal—reproduction—they initiate the process of transformation, which, in the long run, will erode their organization, at least in its original form.

[5] For the analysis of the relationship between organization and evolution, see also Ruiz-Mirazo et al. (2004) and Walsh (2006).

## 2.5 Organization, Constraints, and Morphology

However, for evolution to begin in the first place, there must be an organized system of interdependent parts directed toward its own (or its type's) maintenance (for a critique of this view, see Ruiz-Mirazo et al., 2017). To understand the embodiment of such a system, the central concept of "constraints" has proven useful. Its conceptual history goes back to Gauss' principle of least constraint in classical mechanics. In the context of organization, it refers to the material structure or configuration of parts in a system that has a harnessing or channeling influence on the flow of energy within the system, for example, the structure of an organism's body, which serves as a boundary condition for physical laws. This general idea was described by Franz Reuleaux in his *Theoretical Kinematics* (1875).

Reuleaux is considered the founder of what has later been called "machine morphology." According to Reuleaux, a machine is a "compound of resistant bodies, which is disposed in such a way that mechanical laws of nature are constrained to be effective under certain conditions" (Reuleaux, 1875, p. 38). This means that the effectiveness of a machine depends on the disposition of its parts, the structure of the whole, or its morphology. Morphology works by constraining the laws of nature. The machine does not introduce additional laws of nature; it simply channels or harnesses general laws through its morphology.

A hundred years later, Michael Polanyi applied this line of reasoning to biological systems. According to Polanyi, an organism has the same general makeup as a machine: its bodily structure serves as a boundary condition harnessing physical-chemical processes. In the case of the organism, this harnessing serves its organic functions (1968, p. 1308) Thus, quite surprisingly, life's irreducible structure rests on the very thing living beings have in common with machines: their specific structure (or morphology) that functions as a boundary condition in constraining laws of nature.

Starting in the late 1960s, Howard Pattee elaborated on this by stressing that it is not just the possession of functional constraints that is unique to living beings but the production and coordination of these constraints *by* the system itself. As he put it in 1971: "Life is distinguished from inanimate matter by the co-ordination of its constraints" (Pattee, 1971, p. 273). Organisms are embodied structures that produce their own structure, which feeds back on itself by maintaining and regenerating it. Thus, the boundary conditions or "constraints" of the system are, in the case of organisms, self-imposed. The structure of organismic bodies channels the energy in such a way that the body is preserved or rebuilt. The basic pattern is that of a cycle.

In recent years, a more detailed and precise rendering of this pattern has been provided by Alvaro Moreno and his collaborators. Since the early 1990s, his group has been describing the circular organization of systems on the basis of their components functioning as constraints. In their view, local constraints within the system are generated by the activity of components of the system (Moreno et al., 1994, p. 17; see also Ruiz-Mirazo & Moreno in this volume). They call the resulting system an "autonomous organization" since the system itself generates and regenerates its constraints.

Stuart Kauffman called this circular organization "a virtuous cycle," a cycle of works and constraints: The work of the system generates constraints, namely, precisely those constraints required for the work to be done. According to Kaufman, this cycle is "the heart of a new concept of 'organization'" (Kauffman, 2000, p. 4).

In the last few years, Matteo Mossio has further elaborated on these matters. According to Mossio and his colleagues, biological organization is characterized by the fact that it realizes a specific kind of causal regime. This regime is based on nothing but the material structure of an organism acting as constraints for the physical laws. Because the constraints within the organization are mutually determined, the "organizational closure" of organisms consists in a "closure of constraints" and therefore in a biological self-determination (Montévil & Mossio, 2015, p. 180).

An important consequence of this account is that biological autonomy, in the double sense of biology as a distinct discipline and of organisms as self-determining systems, is entirely based on structures. Nothing but the structure of an organism embodies the constraints that effectively control the boundary conditions for the laws of nature. Biological autonomy is grounded in the material form of living bodies. Biology's distinct causal regimes, once referred to as "life-forces," are embodied in the forms of organisms.

With this emphasis on form, the biological subdiscipline of *morphology*, which has been marginalized for over a century now, is again taking center stage. Ultimately, it is morphology that provides the basis for the organism as an integrated autonomous system because it provides the only factor beyond the laws of nature that is specific to organisms. Insofar as organisms are considered to be autonomous, they are determined by their form. Form is the only additional factor that distinguishes organisms from inorganic bodies. This is true, at least at the explanatory level, because forms provide the only specific biological causal factor. To put it bluntly: The only life forces that exist are life forms.

Thus, morphology, the study of forms, is the fundamental explanatory principle of biology. It has always been fairly easy for biologists to identify functions in living beings. Aristotle was famously prolific at it, and his well-known functional categories, such as nutrition, growth, and reproduction, are still being used today. However, although they may still define what it means to be alive, functions do not necessarily provide causal understanding of processes. In biology, this is done by identifying mechanisms; and mechanisms are based on morphology, because it is morphology that identifies the structures that function as (self-)constraints within natural organizations, establishing them as a distinct type of material bodies.

Organic forms, then, are the mediators for the realization of biological organizations. They instantiate these organizations in specific living bodies; in their function as particular "constraints," they enable the causal interdependence of the components and the self-referentiality of the whole system. Thus, "organization" and "form" are two complementary aspects of living bodies: the first refers to the causal pattern that constitutes the unity of the system and the second to the individuality of the system and the specific material "constraints" by which this causal pattern is realized and instantiated in concrete living beings. Or, in other words, "organization" provides the law-like universal feature of all living beings (existent and potential), "forming" the physical realization of its causal pattern in distinct instances. Biological explanations demonstrate how forms are effective as functions, i.e., how they are integrated in functional closure. The fixed form of the heart chambers (in a particular individual or in the type of individuals of a certain class) explains how this form constrains the general laws in order to achieve closure.

"Organization" and "form" both fulfill *descriptive* and *explanatory* functions in biology, albeit at different levels: The first visible feature of living beings is, of course, their form; forms are *described* and are the basis for biological classifications (as they indicate genealogical relationships). However, forms also *explain* (and only they can do that) how the forces and energy flows in an organism are channeled to realize the functional closure that is characteristic of every living being. "Organization," on the other hand, is *descriptive* with respect to the causal pattern that all living beings have in common; this pattern, causal "cyclicity" or functional "closure," is identified when an entity is described as being organized.[6] However, on a more abstract level, "organization" gives the *explanation* to the fact that all living beings share a certain functional order.[7] This explanation consists in the specification of the causal pattern or the working order of every organism, namely, the self-referentiality of all their activities, their orientation toward self-maintenance (what the developmental biologist Wilhelm Roux once called the "autophely" or "self-utility" of organisms; Roux, 1895, p. 58). Since "organization" specifies this causal and functional pattern common to all living beings, it grounds the biological approach toward nature. At the same time, as there are living beings on earth that do not always behave autophelically, "organization" also marks the end of the biological perspective focused on autophely: "Man has reached a level of existence that stands above purpose. It is his distinctive value that he can act without purpose" (Simmel, 1918, p. 28).

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[6] For Kant, this identification procedure takes place in reflective judgments, and he is very clear about his view that they are not explanatory, but descriptive: "positing ends of nature in its products, insofar as it constitutes a system in accordance with teleological concepts, belongs only to the description of nature" (Kant, 1790, p. 417).

[7] "Form," however, is also a concept that involves abstractions. In most biological contexts, it does not refer to individual bodies but to structural aspects that numerous individuals (of one species or of another taxonomic unit) have in common. Nevertheless, for every specific causal interaction, it is the realization of one form in an individual organism that serves as constraint.

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